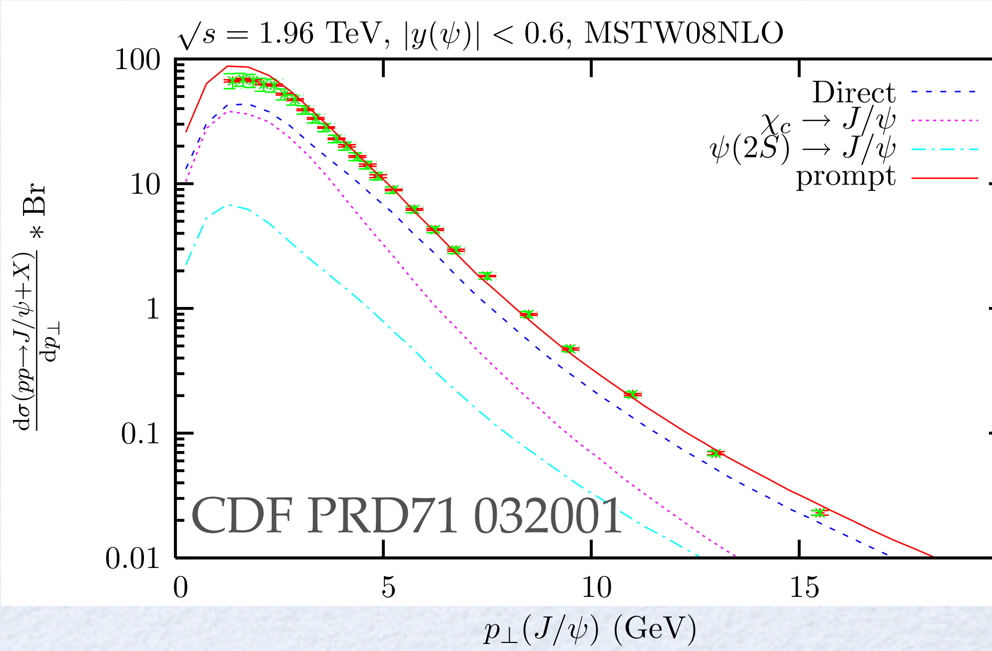
Study of Quarkonium $\to \mu\mu$ production at LHCb

Deep Inelastic Scattering 2011
Newport News, VA

CERN
Ulrich Kerzel

INTRODUCTION

- Quarkonia production mechanism challenging for theory
- Several contribution
  - Colour Singlet (CS)
  - Colour Octet (CO)
  - Colour Evaporation (CE)
  - Inclusion of higher order terms (NRQCD)
- Example: J/ψ
  - Leading-order CS undershoots measured cross-section
  - CO does not provide a scale but can be fitted to match the data
    ➥ but predicts wrong polarisation
  - NRQCD factorisation valid at low p_t?
  - Predictions on χ_c feed-down contradict low energy data from PHENEX?

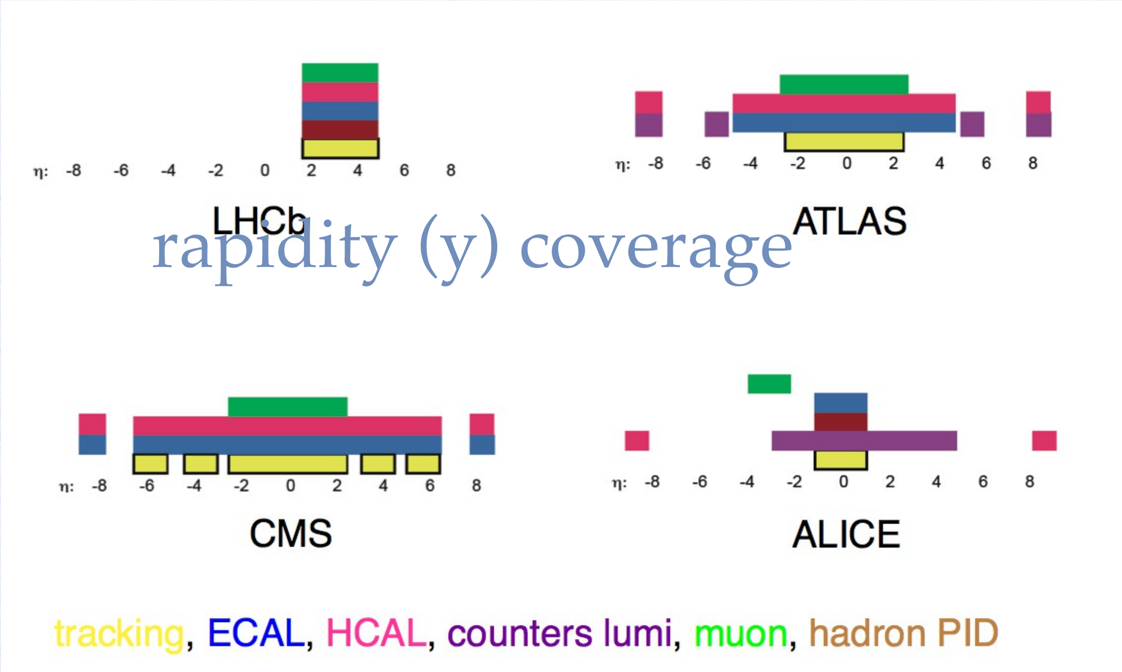


L. Harland-Lang

- Precision measurements at LHC(b) paramount for understanding Quarkonia

INTRODUCTION

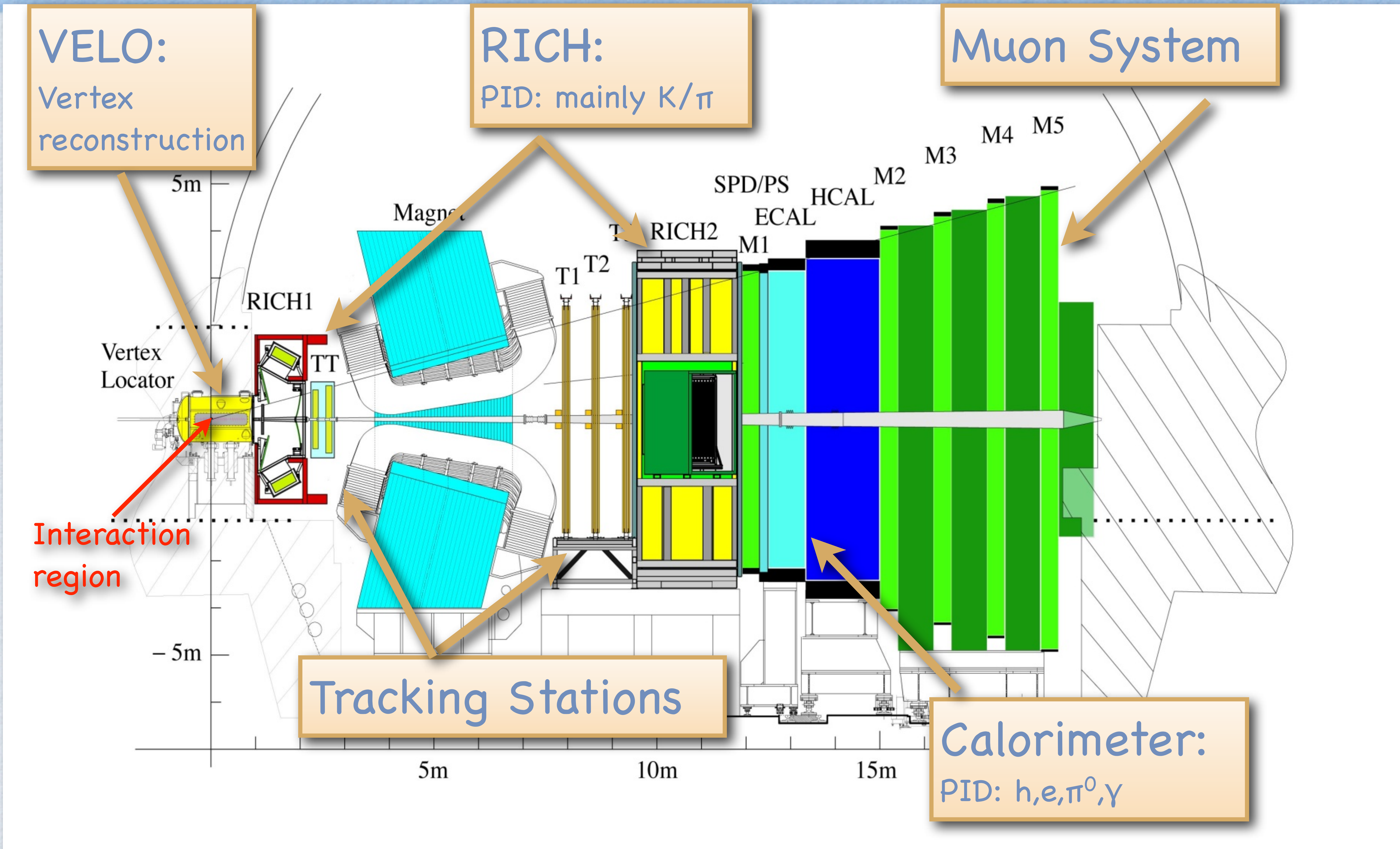
- LHCb:
  - forward arm spectrometer: unique rapidity range
    ➥ complementary to ATLAS/CMS/ALICE



rapidity (y) coverage

- In this talk:
  - J/ψ cross-section
  - $\Upsilon(1S)$ cross-section
  - Observation of double J/ψ production
- Please refer to dedicated talks for
  - Exclusive χ_c production
  - Ratio of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$

LHCB



VELO:
Vertex reconstruction
RICH:
PID: mainly K/π
Muon System
M4
M5
M3
M2
SPD/PS
HCAL
ECAL
5m
Magnet
RICH2
M1
T1
T2
RICH1
Vertex Locator
TT
Interaction region
– 5m
Tracking Stations
5m
10m
15m
Calorimeter:
PID: h,e,π⁰,γ

hep-ex/1103.0423

J/ψ cross-section

Submitted to EPJC

- Analysis strategy:
  - Measure double differential cross section in rapidity and p_t

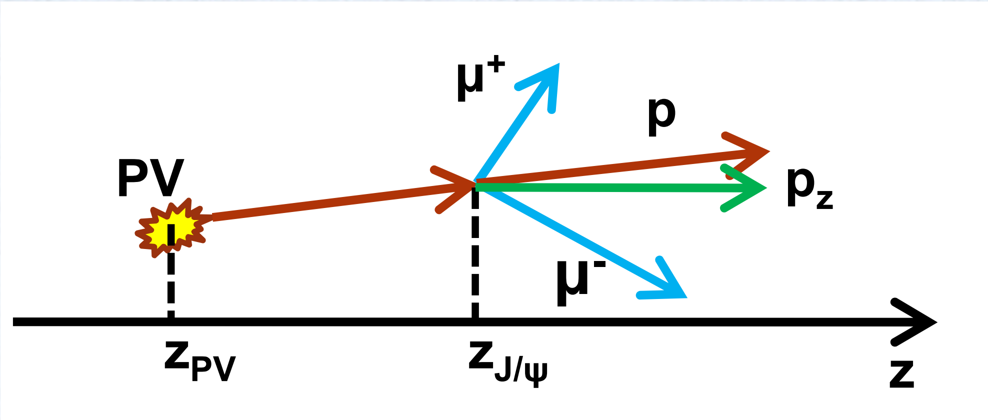
$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\,\mathrm{d}p_\mathrm{T}} = \frac{N\left(J/\psi \to \mu^+\mu^-\right)}{\mathscr{L} \times \varepsilon_\mathrm{tot} \times \mathscr{B}\left(J/\psi \to \mu^+\mu^-\right) \times \Delta y \times \Delta p_\mathrm{T}}$$

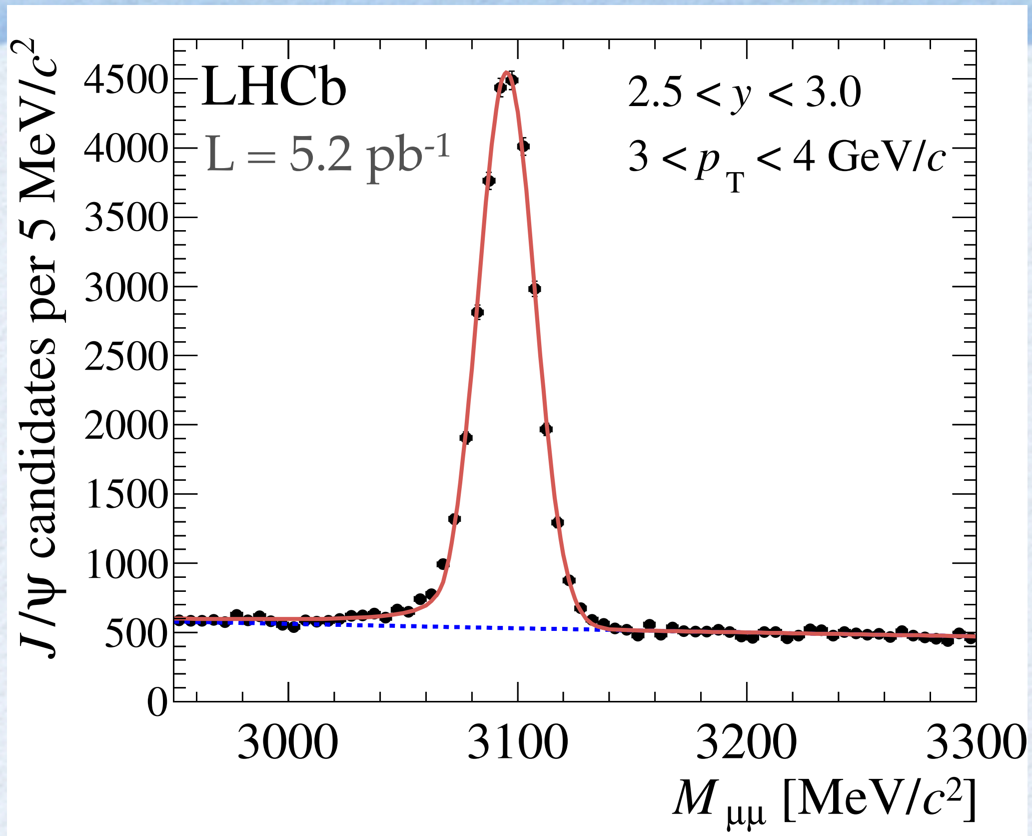
  - μμ final state
  - $0 < p_t < 14$ GeV, $2 < y < 4.5$
  - Data from Sep. 2010, integrated luminosity: 5.2 pb^{-1}
  - Consider both
    - Prompt J/ψ
    - J/ψ from *b* decays.
  - Efficiencies calculated from simulation (assuming unpolarised J/ψ)

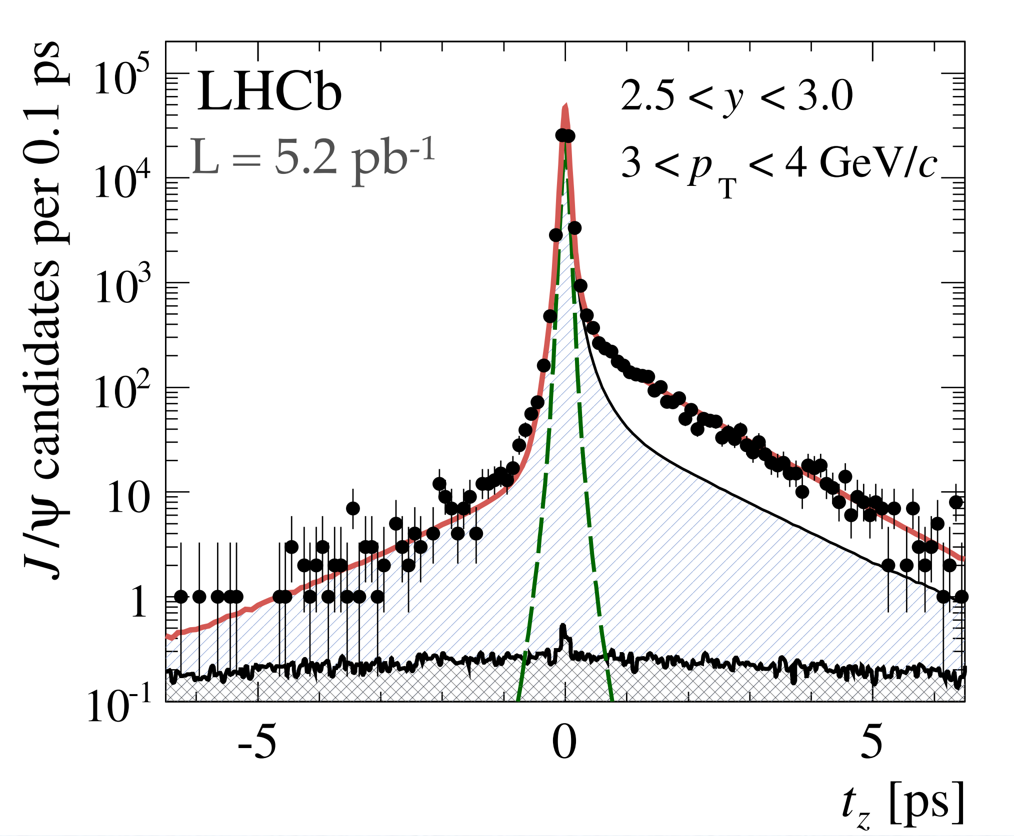
J/ψ cross-section

- #J/ψ→μμ estimated from fit to inv. mass spectrum
- Fraction from *b* decays extracted using pseudo-propertime t_z:

$$t_z = \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z}$$



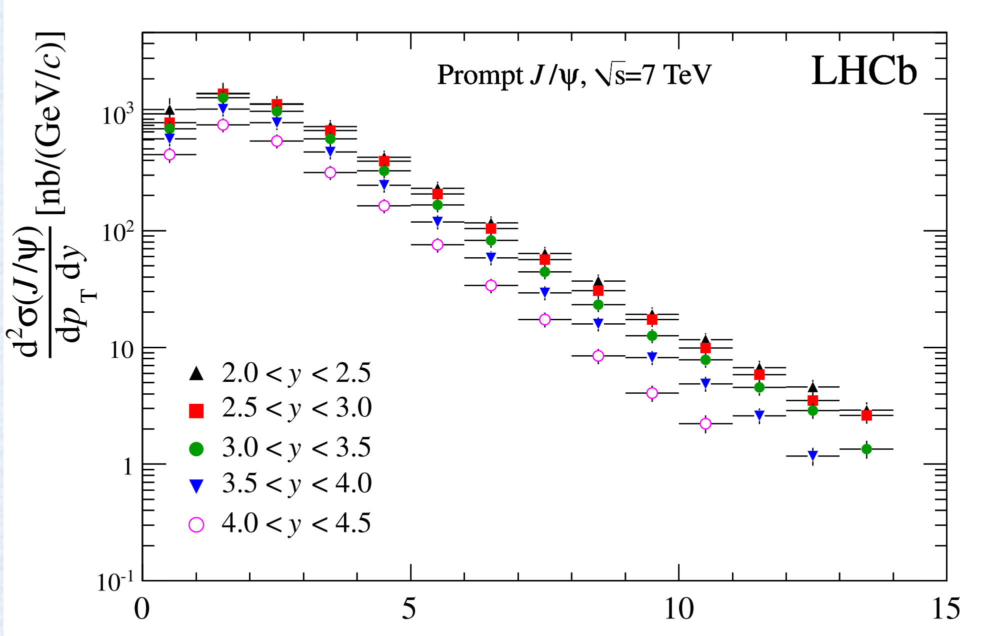


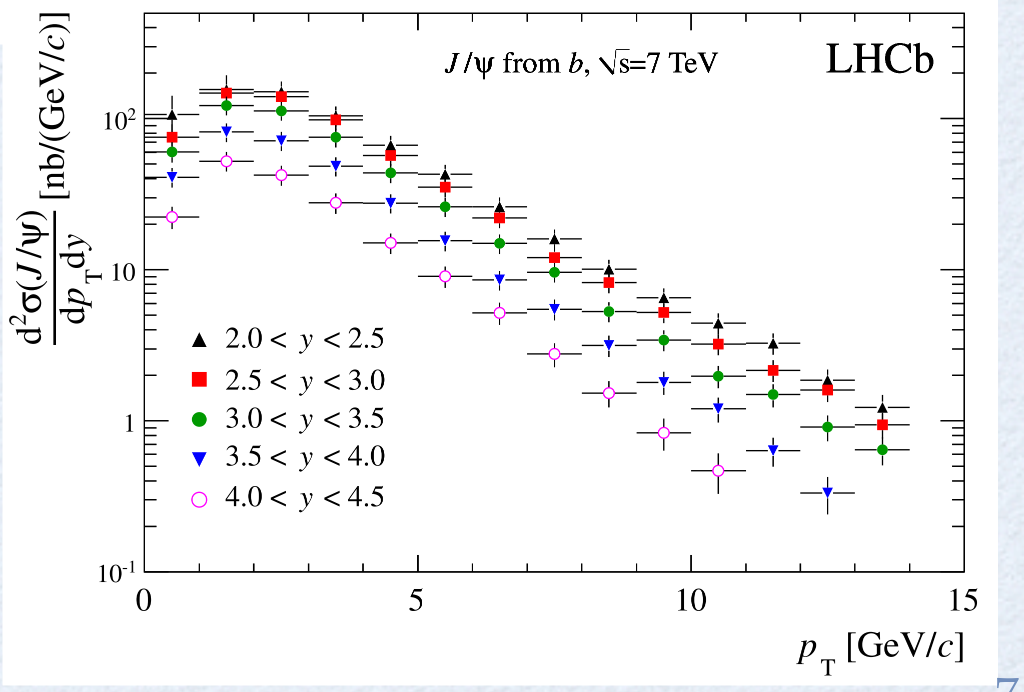


RESULTS

$$\sigma_{\text{prompt}} = 10.52 \pm 0.04\ (\text{stat.})\ \pm 1.40\ (\text{syst.})\ ^{+1.64}_{-2.20}\ (\text{pol.})\ \mu\text{b}$$

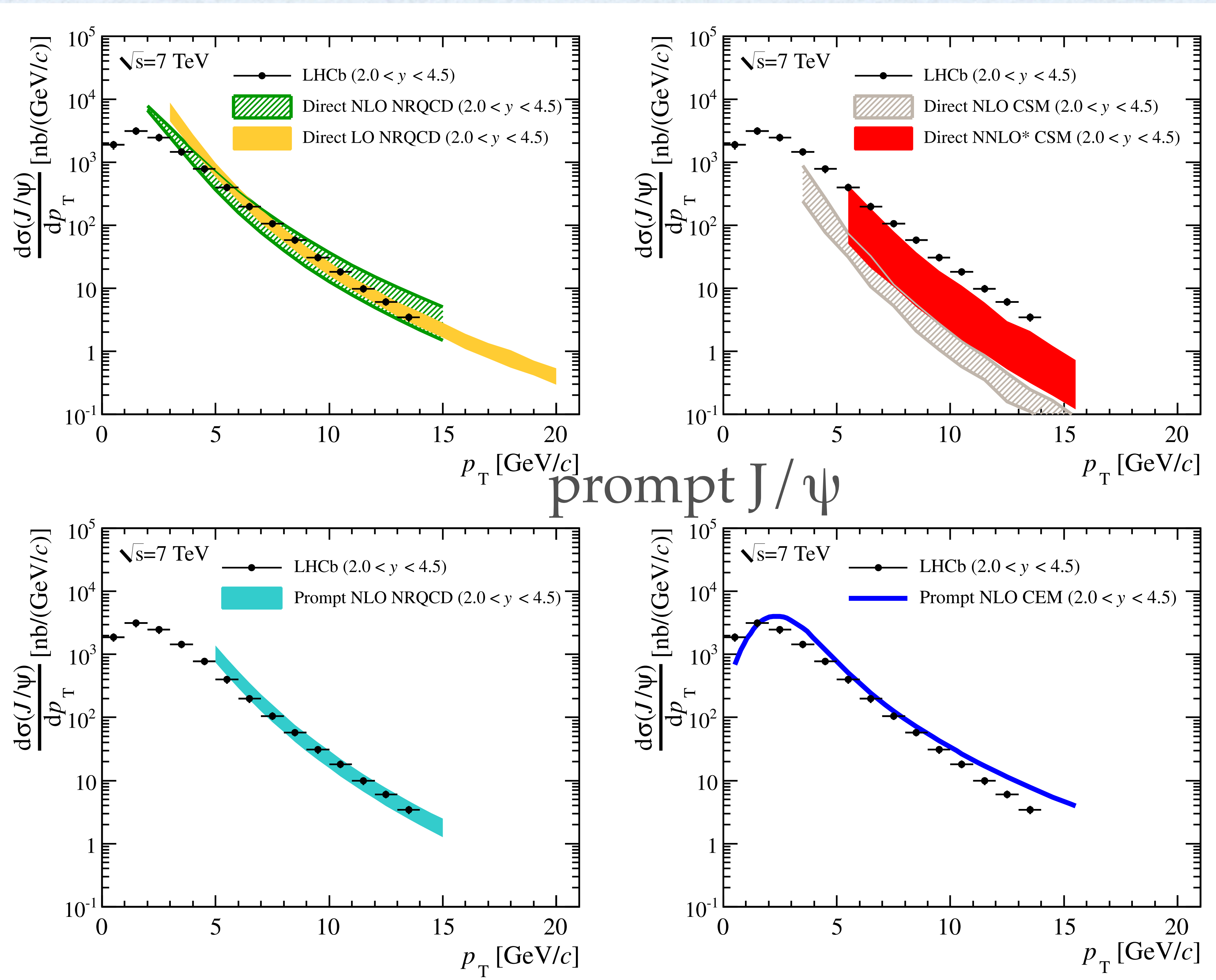
$$\sigma_{\text{from } b} = 1.14 \pm 0.01\ (\text{stat.})\ \pm 0.16\ (\text{syst.})\ \mu\text{b}$$



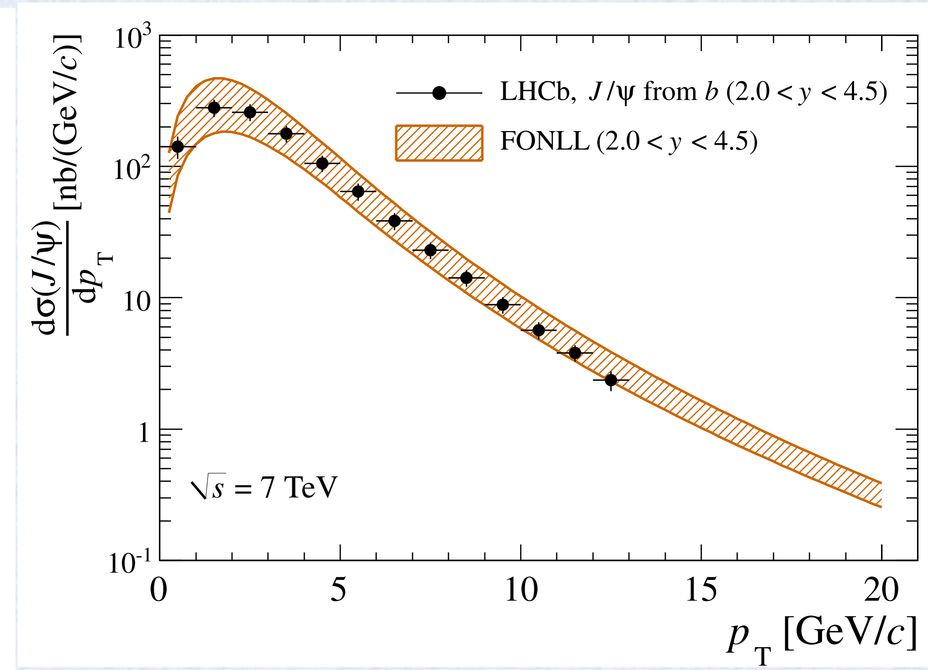


Source	Systematic uncertainty (%)
Correlated between bins	
Inter-bin cross-feed	0.5
Mass fits	1.0
Radiative tail	1.0
Muon identification	1.1
Tracking efficiency	8.0
Track χ^2	1.0
Vertexing	0.8
GEC	2.0
$\mathcal{B}(J/\psi \to \mu^+\mu^-)$	1.0
Luminosity	10.0
Uncorrelated between bins	
Bin size	0.1 to 15.0
Trigger	1.7 to 4.5
Applied only to J/ψ from b cross-sections, correlated between bins	
GEC efficiency on B events	2.0
t_z fits	3.6
Applied only to the extrapolation of the $b\bar{b}$ cross-section	
b hadronisation fractions	2.0
$\mathcal{B}(b \to J/\psi X)$	9.0

COMPARISON TO THEORY



prompt J/ψ



J/ψ from *b*

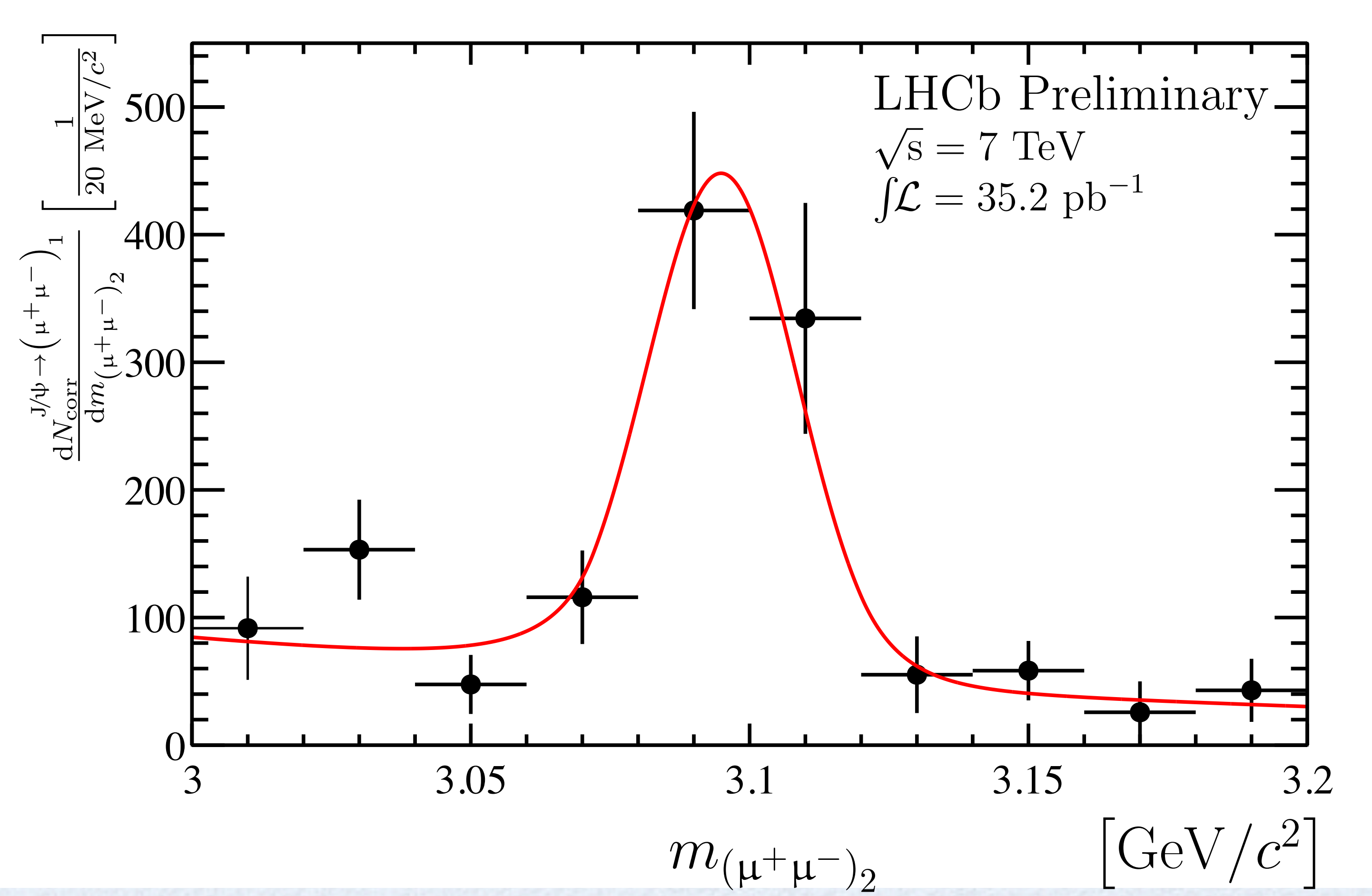
- Generally reasonable agreement between theory and measurement

Double J/ψ production

- First seen: NA3 (1982) in π-platinum (Phys. Lett. B114,457)
- Main production mechanism at LHC: gluon-gluon fusion
- Predicted (prompt) cross-section (hep-ph/1101.5881)
  - 4π: $\sigma^{J/\psi J/\psi} \sim 24.5$ nb
  - For LHCb: $\sigma^{J/\psi J/\psi} \sim 4.34$ nb (w/o ISR) or 4.14 nb (w/ ISR),

- Data recorded in 2010, integrated luminosity 35.2 pb^{-1}
- Signal extraction:
  - 4 muon combination $(\mu^+\mu^-)_1(\mu^+\mu^-)_2$ from common vertex
  - Each di-muon pair compatible with J/ψ hypothesis
  - Efficiency calculated from simulation (reconstruction and event selection) and data (μ-ID , trigger)

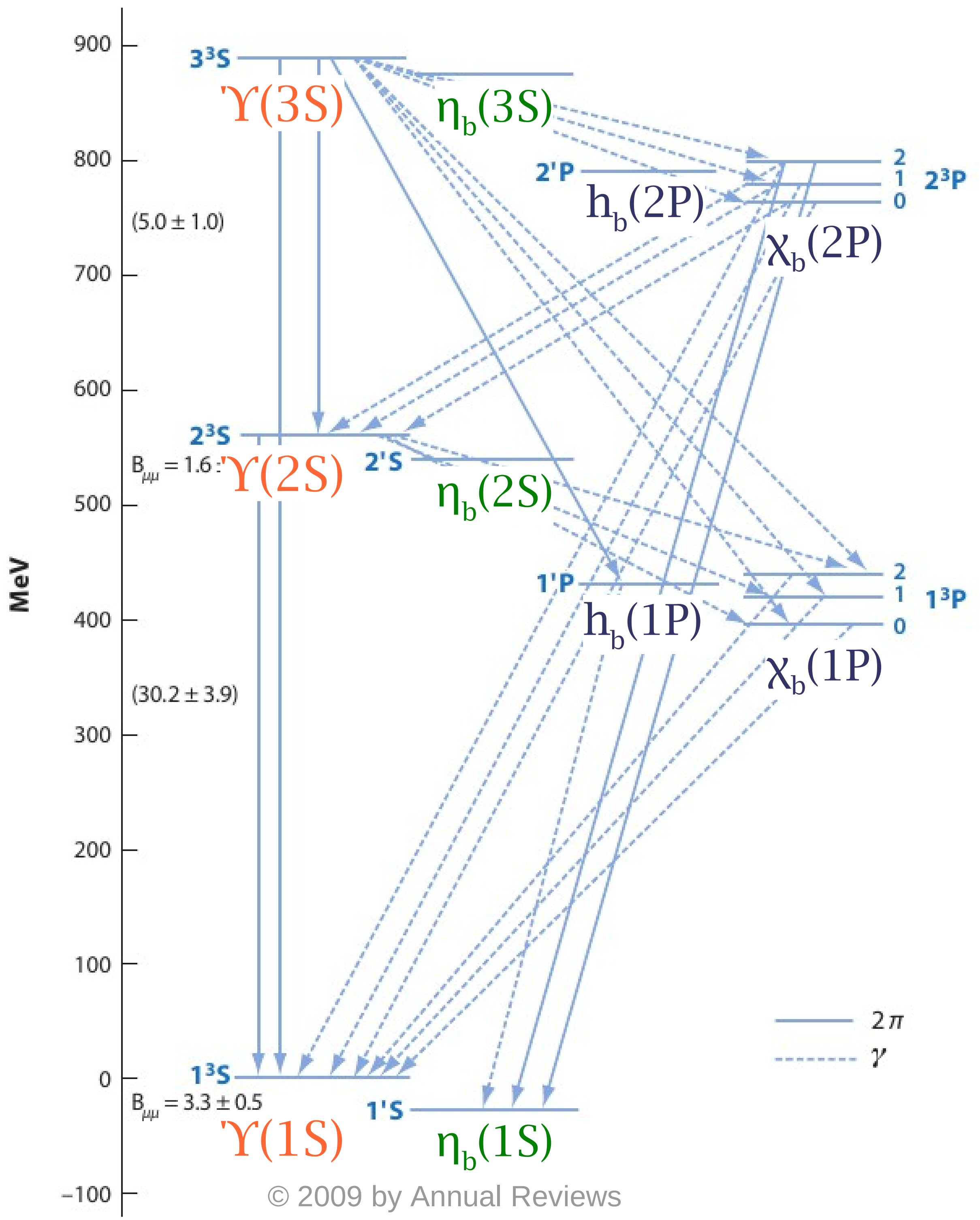
Results



Source	Systematic uncertainty [%]
Per-event efficiency	3
Trigger efficiency	8
Global event cuts	2
MC-data difference	3
Muon identification	2×1.1
Tracking	4×4
Luminosity	10
Total	21

- $N^{J/\psi J/\psi} = 139.6 \pm 17.8$
- $\Delta\chi^2/\text{ndof} = 61.3/8 \Leftrightarrow > 6\sigma$
- $\sigma^{J/\psi J/\psi} = 5.6 \pm 1.1$ (stat.) ± 1.2 (syst.) nb (theory: ~4.14...4.34 nb)

Υ production



Bottomonium states

Two sources of Υ(1)

- Direct production:

$$pp \to b\bar{b} + X$$
$$\to \Upsilon(1S) + X$$

- Feed-down from higher states

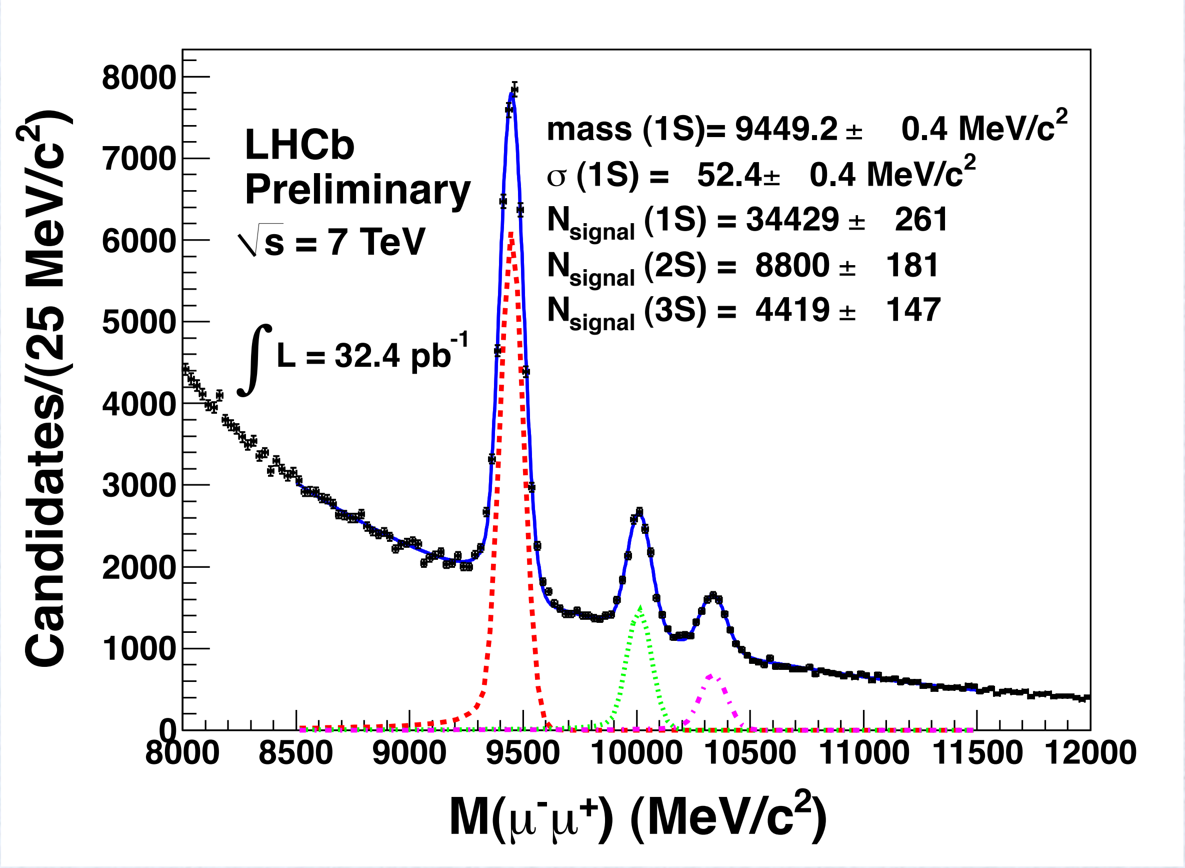
$$pp \to b\bar{b} + X$$
$$\to \chi_b$$
$$\to \Upsilon(1S) + \gamma$$
$$\to \Upsilon(nS)$$
$$\to \Upsilon(1S) + X$$

Υ(1S) cross-section

- Analysis strategy:
  - Measure double differential cross section in rapidity and p_t

$$\frac{d^2\sigma}{dp_T dy} = \frac{N(\Upsilon(1S) \to \mu^+\mu^-)}{\mathcal{L} \times \varepsilon \times \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) \times \Delta y \times \Delta p_T},$$

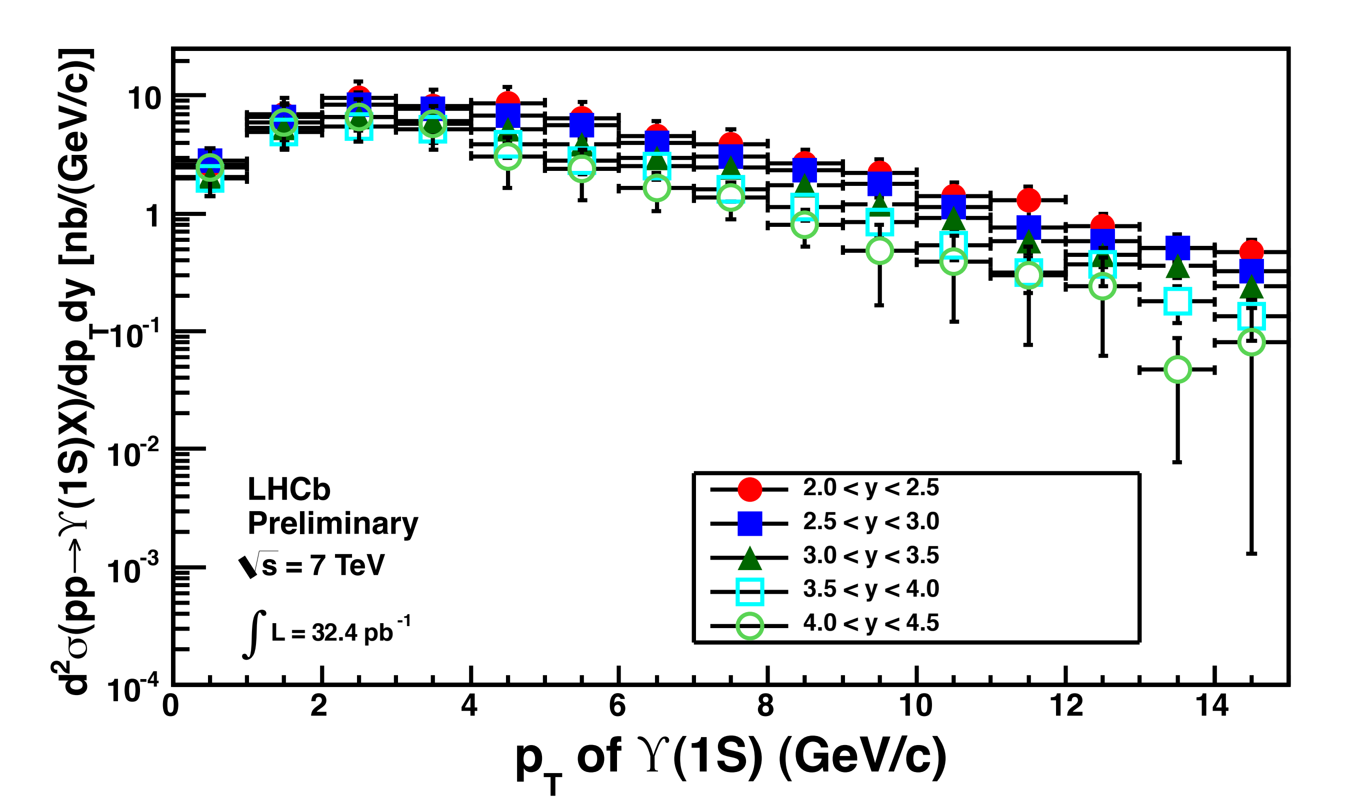
- μμ final state
- $0 < p_t < 15$ GeV, $2 < y < 4.5$
- Data from April - Nov. 2010, integrated luminosity: 32.4 pb^{-1}
- Acceptance and reconstruction efficiencies estimated from simulation, trigger eff. from data



RESULTS

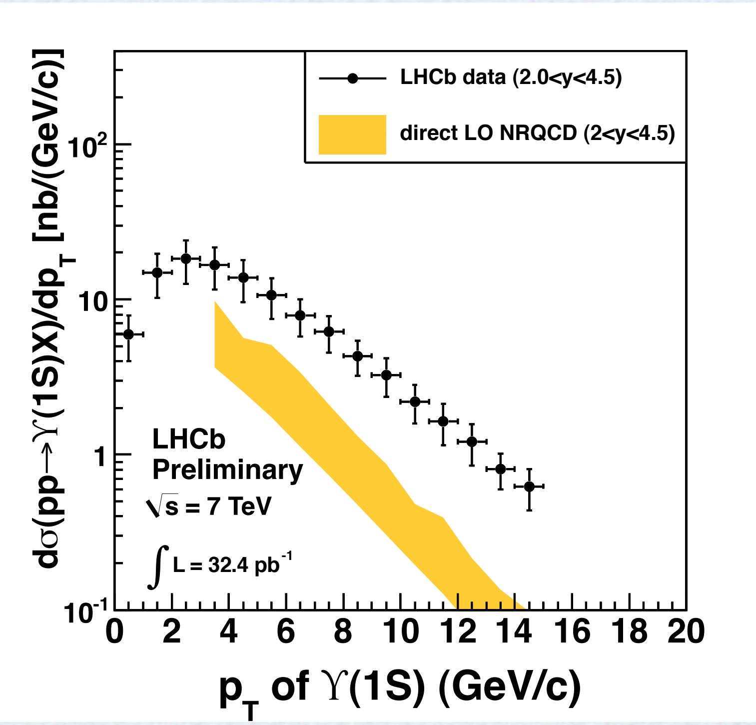
$$\sigma_{\Upsilon(1S)} = 108.3 \pm 0.7\ (\text{stat.})\ ^{+30.9}_{-25.8}\ (\text{syst.})\ \text{nb}$$

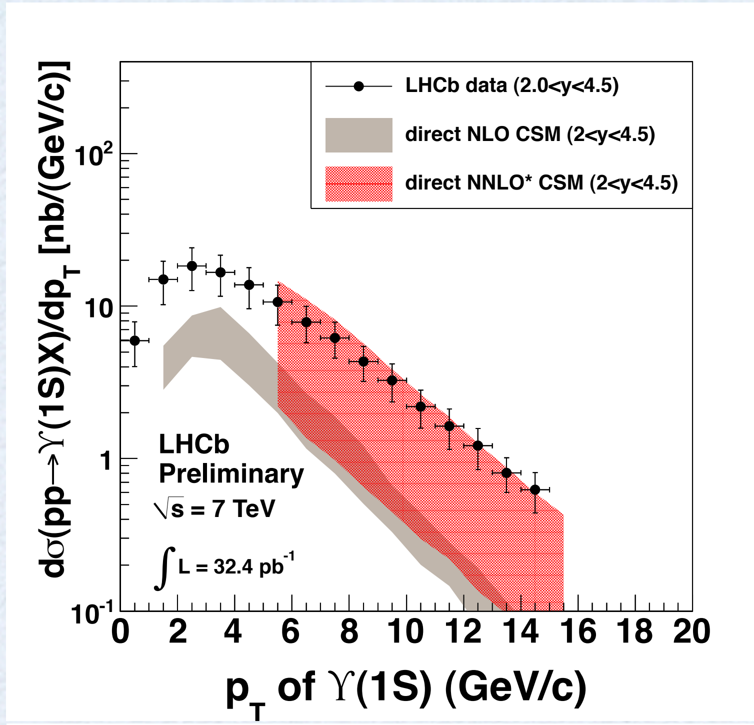
- Sizeable contribution to uncertainties due to unknown Υ polarisation

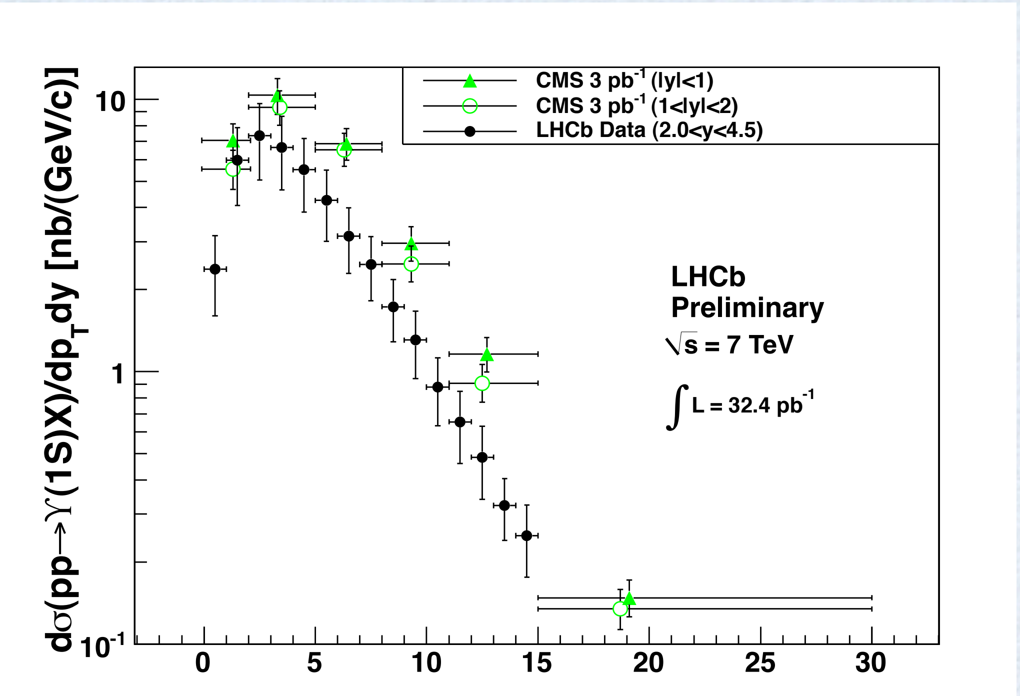


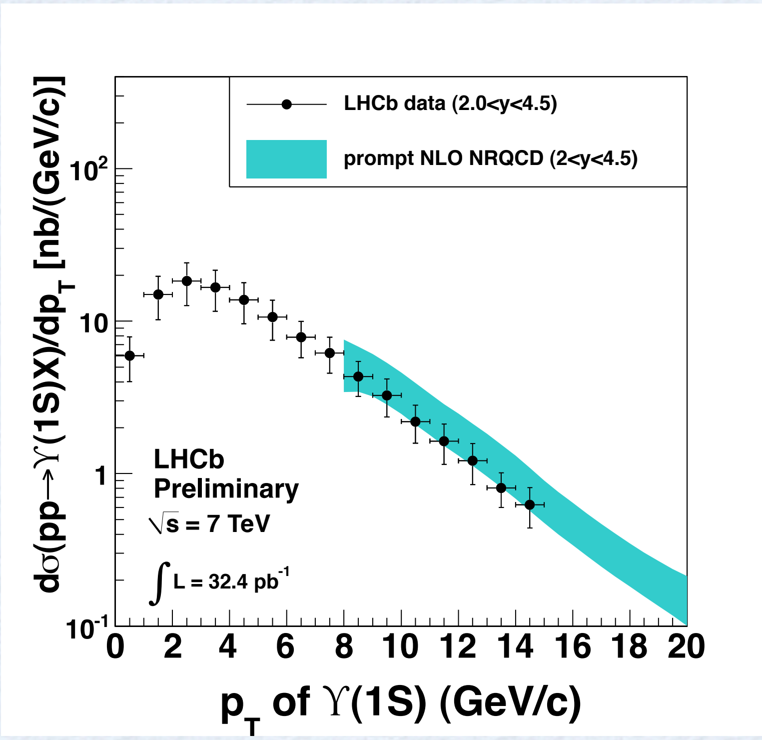
Source	Method	Value
Luminosity	Precision on beam current	10%
Trigger	Difference between J/ψ and Υ(nS) (simulation)	0-67%
Polarisation on acceptance	Extreme polarisation scenarios	0-33%
Polarisation on reconstruction	Extreme polarisation scenarios	0-21%
Choice of fit function	Test different functions	1%
Unknown pt spectrum	Estimate effect of 0.5% p_T resolution	1%
Global event cut (trigger)	Statistical uncertainty on data	2%
Track quality cut	Difference between data and simulation	0.5%/track
Track finding algorithm	Difference between data and simulation	4%/track
Vertexing	Difference between data and simulation	1%
Muon ID	Difference between data and simulation	1.1%

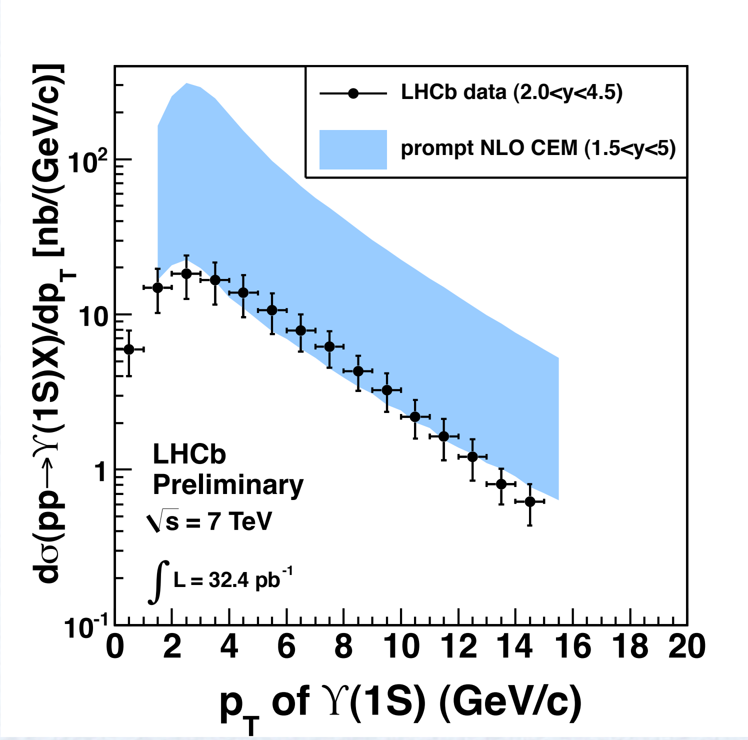
Comparison to theory / CMS

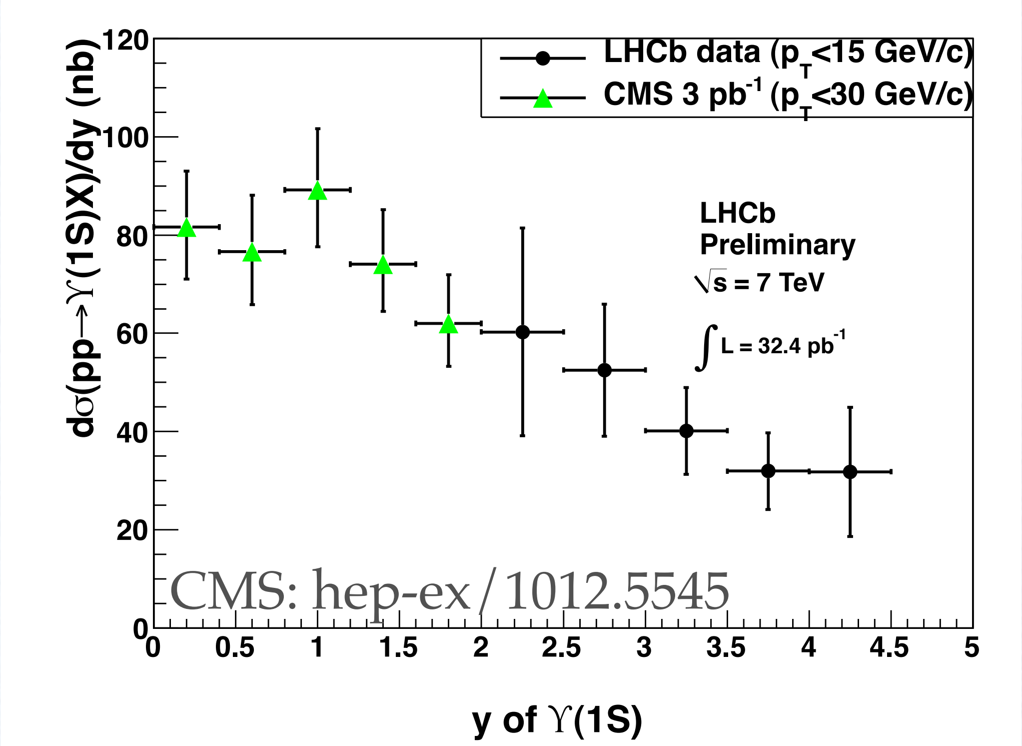










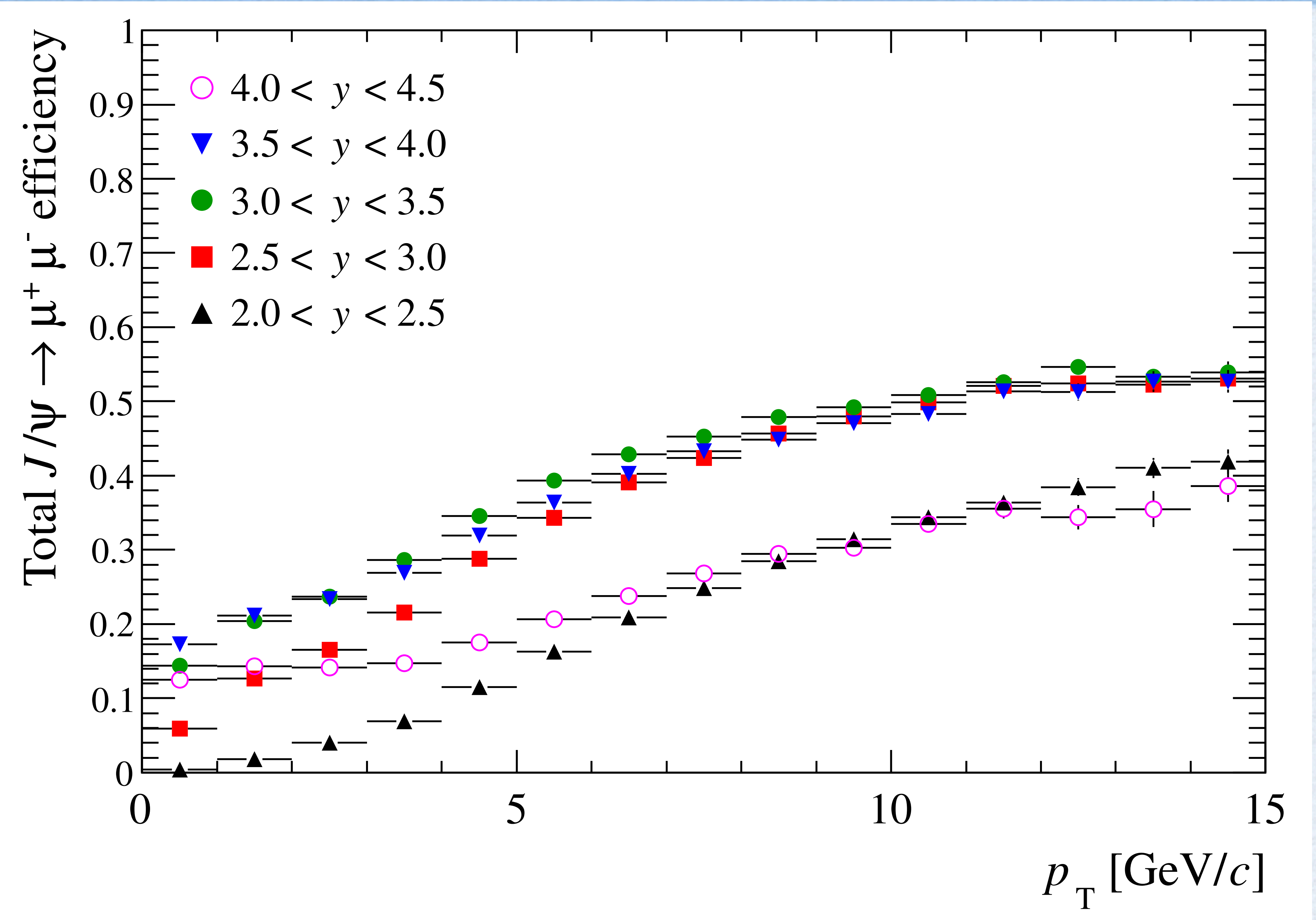


Summary

- First measurements of J/ψ and ϒ(1S) production cross-section using data at $\sqrt{s} = 7$ TeV recorded in 2010 at LHCb
  - Generally good agreement with theory
  - ϒ(1S) measurement complementary to CMS
- Observation of double J/ψ production at LHC
  - First cross-section measurement
    ➥ reasonable agreement with theoretical prediction
- In preparation
  - ψ(2S), ϒ(2S), ϒ(3S) cross section
  - X(3872) quantum numbers J^{PC}
- Dedicated talks for χ_c studies, X(3872) mass

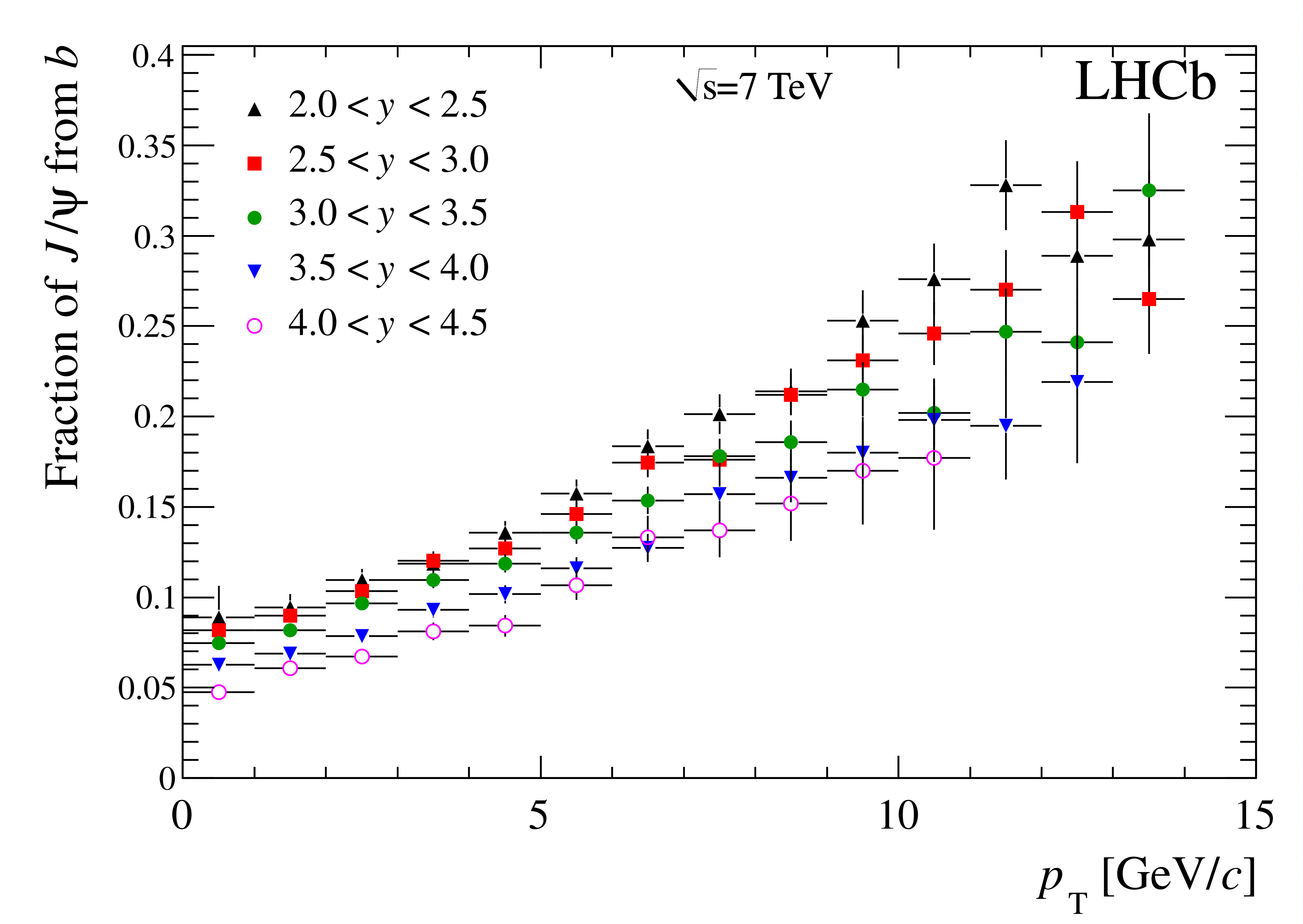
BACKUP

J/ψ efficiency



- Estimated using simulated events

J/ψ FRACTION FROM

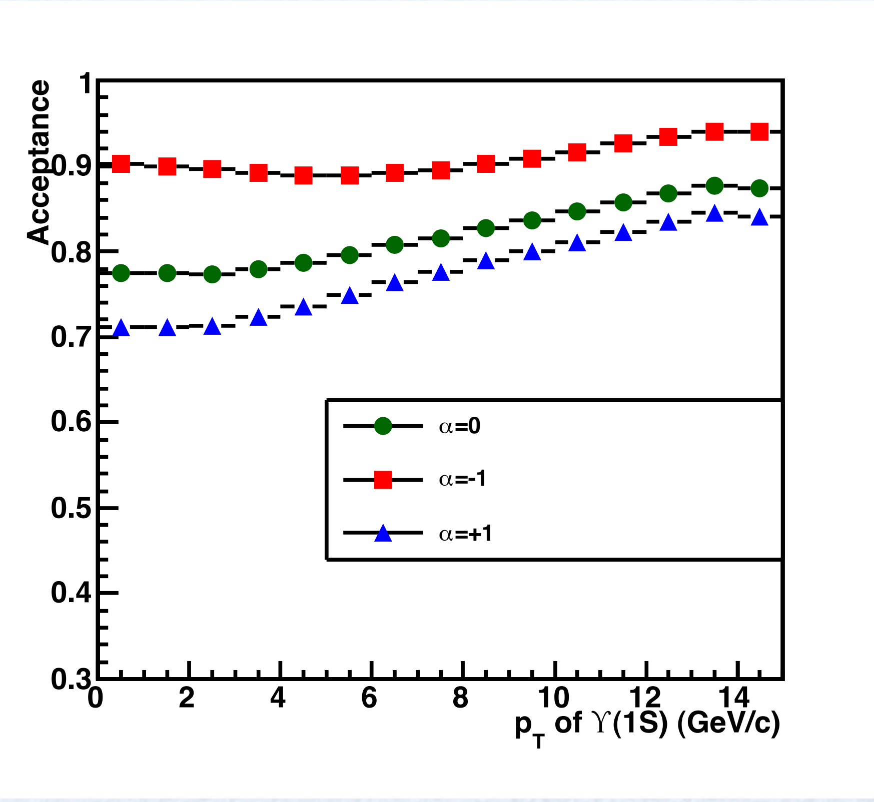


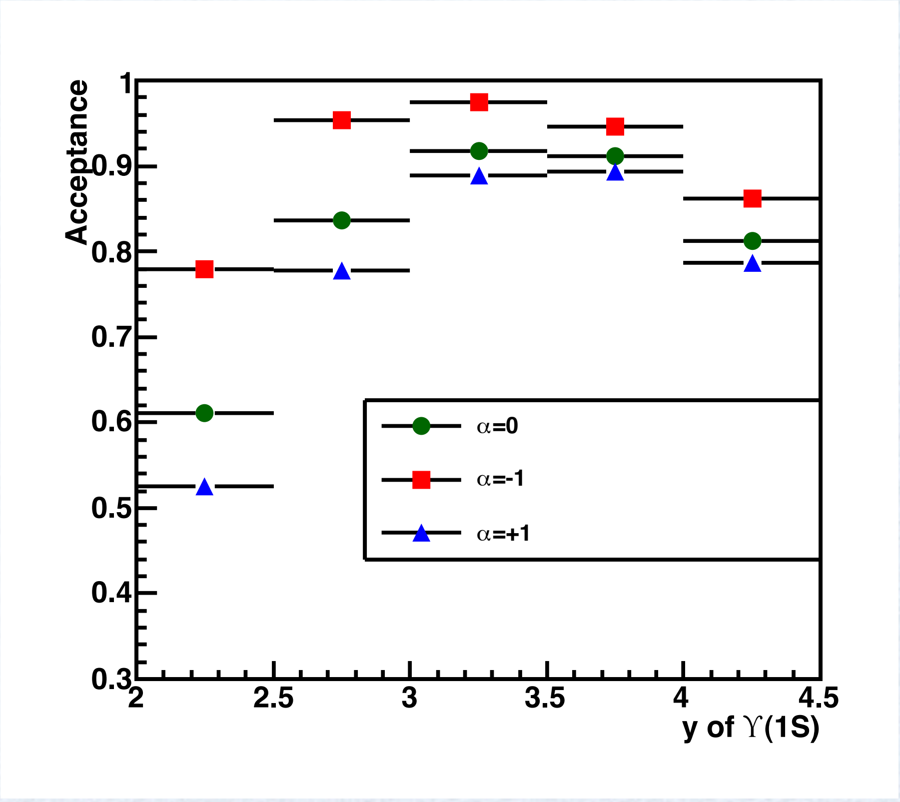
$\Upsilon(1S)$ cross-section

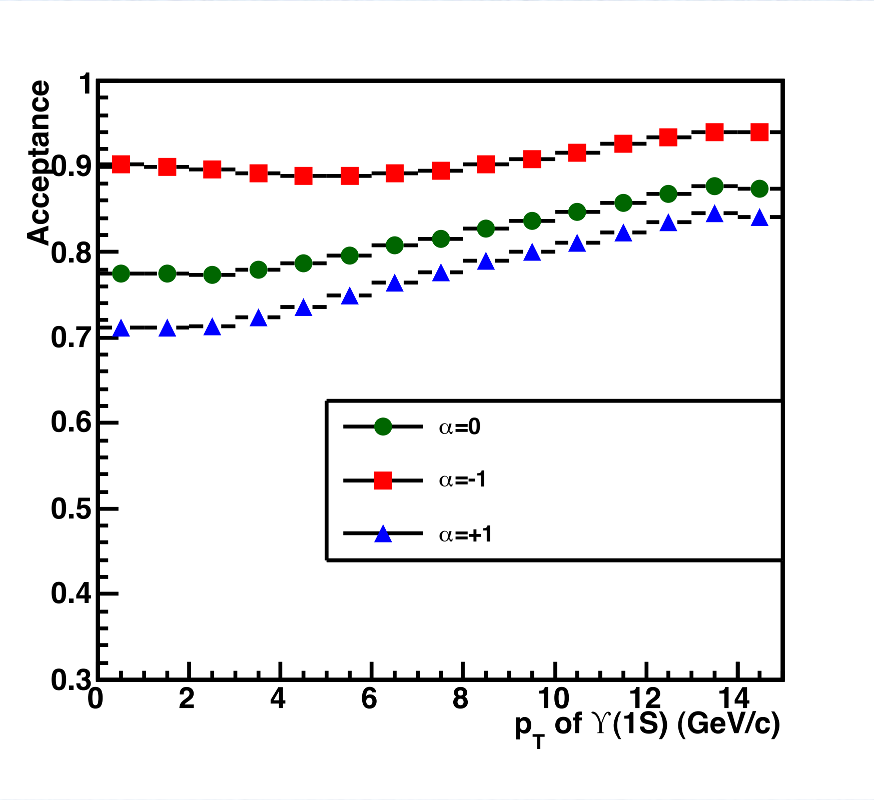
Table 3: $\Upsilon(1S)$ production cross-section results as a function of y and p_T, in nb. The first uncertainty is statistical, the second systematic.

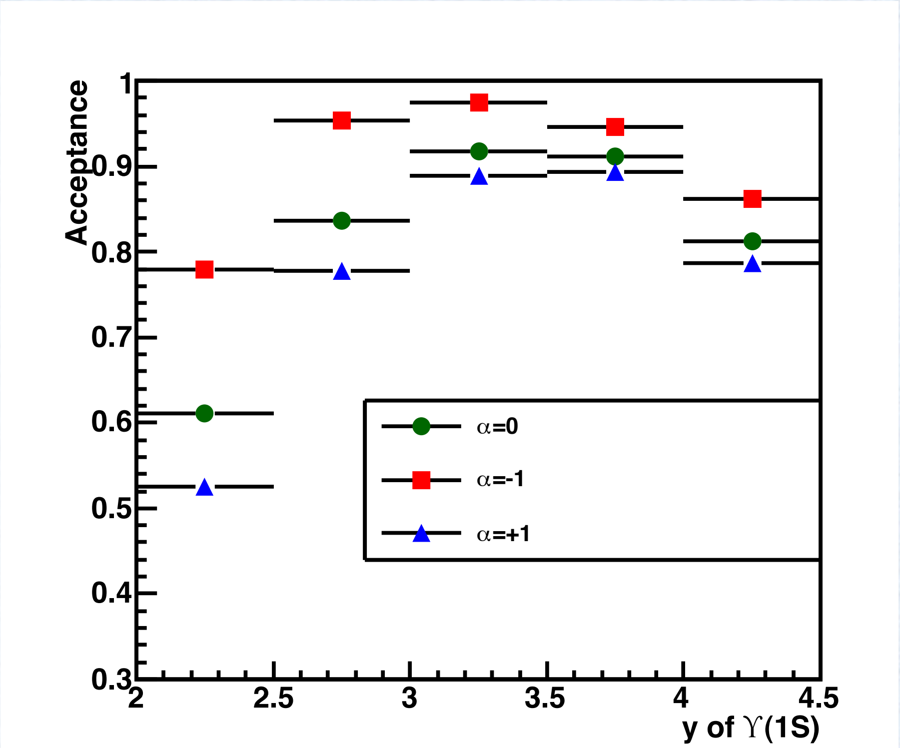
p_T (GeV/c)	$\sigma(2.0 < y < 2.5)$ (nb)	$\sigma(2.5 < y < 3.0)$ (nb)	$\sigma(3.0 < y < 3.5)$ (nb)	$\sigma(3.5 < y < 4.0)$ (nb)	$\sigma(4.0 < y < 4.5)$ (nb)
0 – 1	2.59 ± 0.18 ± 1.00	2.78 ± 0.12 ± 0.77	2.05 ± 0.10 ± 0.48	1.98 ± 0.11 ± 0.55	2.47 ± 0.25 ± 1.04
1 – 2	6.89 ± 0.29 ± 2.69	6.70 ± 0.19 ± 1.82	5.40 ± 0.16 ± 1.24	4.90 ± 0.17 ± 1.30	5.96 ± 0.38 ± 2.40
2 – 3	9.54 ± 0.33 ± 3.61	8.48 ± 0.22 ± 2.32	6.55 ± 0.18 ± 1.51	5.45 ± 0.18 ± 1.37	6.69 ± 0.40 ± 2.59
3 – 4	8.26 ± 0.30 ± 3.03	7.74 ± 0.21 ± 2.03	6.16 ± 0.17 ± 1.40	5.20 ± 0.18 ± 1.23	5.86 ± 0.36 ± 2.31
4 – 5	8.67 ± 0.30 ± 3.08	6.72 ± 0.19 ± 1.73	5.16 ± 0.16 ± 1.13	3.92 ± 0.15 ± 0.92	3.07 ± 0.23 ± 1.40
5 – 6	6.51 ± 0.26 ± 2.24	5.59 ± 0.17 ± 1.40	3.89 ± 0.14 ± 0.84	2.85 ± 0.13 ± 0.66	2.41 ± 0.19 ± 1.08
6 – 7	4.59 ± 0.21 ± 1.52	4.01 ± 0.15 ± 0.98	2.99 ± 0.12 ± 0.62	2.50 ± 0.12 ± 0.54	1.64 ± 0.15 ± 0.57
7 – 8	3.89 ± 0.19 ± 1.25	3.04 ± 0.13 ± 0.72	2.47 ± 0.11 ± 0.50	1.61 ± 0.09 ± 0.35	1.37 ± 0.14 ± 0.46
8 – 9	2.65 ± 0.16 ± 0.82	2.36 ± 0.11 ± 0.54	1.72 ± 0.09 ± 0.35	1.13 ± 0.08 ± 0.25	0.80 ± 0.10 ± 0.26
9 – 10	2.23 ± 0.14 ± 0.65	1.78 ± 0.09 ± 0.40	1.19 ± 0.07 ± 0.24	0.84 ± 0.07 ± 0.19	0.49 ± 0.08 ± 0.31
10 – 11	1.41 ± 0.11 ± 0.40	1.14 ± 0.07 ± 0.25	0.92 ± 0.06 ± 0.18	0.53 ± 0.05 ± 0.12	0.39 ± 0.07 ± 0.26
11 – 12	1.31 ± 0.10 ± 0.36	0.76 ± 0.06 ± 0.16	0.58 ± 0.05 ± 0.12	0.32 ± 0.04 ± 0.10	0.30 ± 0.07 ± 0.21
12 – 13	0.77 ± 0.08 ± 0.21	0.59 ± 0.05 ± 0.13	0.45 ± 0.04 ± 0.09	0.37 ± 0.04 ± 0.12	0.24 ± 0.06 ± 0.17
13 – 14	0.51 ± 0.06 ± 0.14	0.51 ± 0.05 ± 0.11	0.36 ± 0.04 ± 0.07	0.18 ± 0.03 ± 0.05	0.05 ± 0.02 ± 0.03
14 – 15	0.47 ± 0.06 ± 0.13	0.32 ± 0.04 ± 0.07	0.24 ± 0.03 ± 0.05	0.13 ± 0.03 ± 0.04	0.08 ± 0.03 ± 0.07

ϒ(1S) polarisation

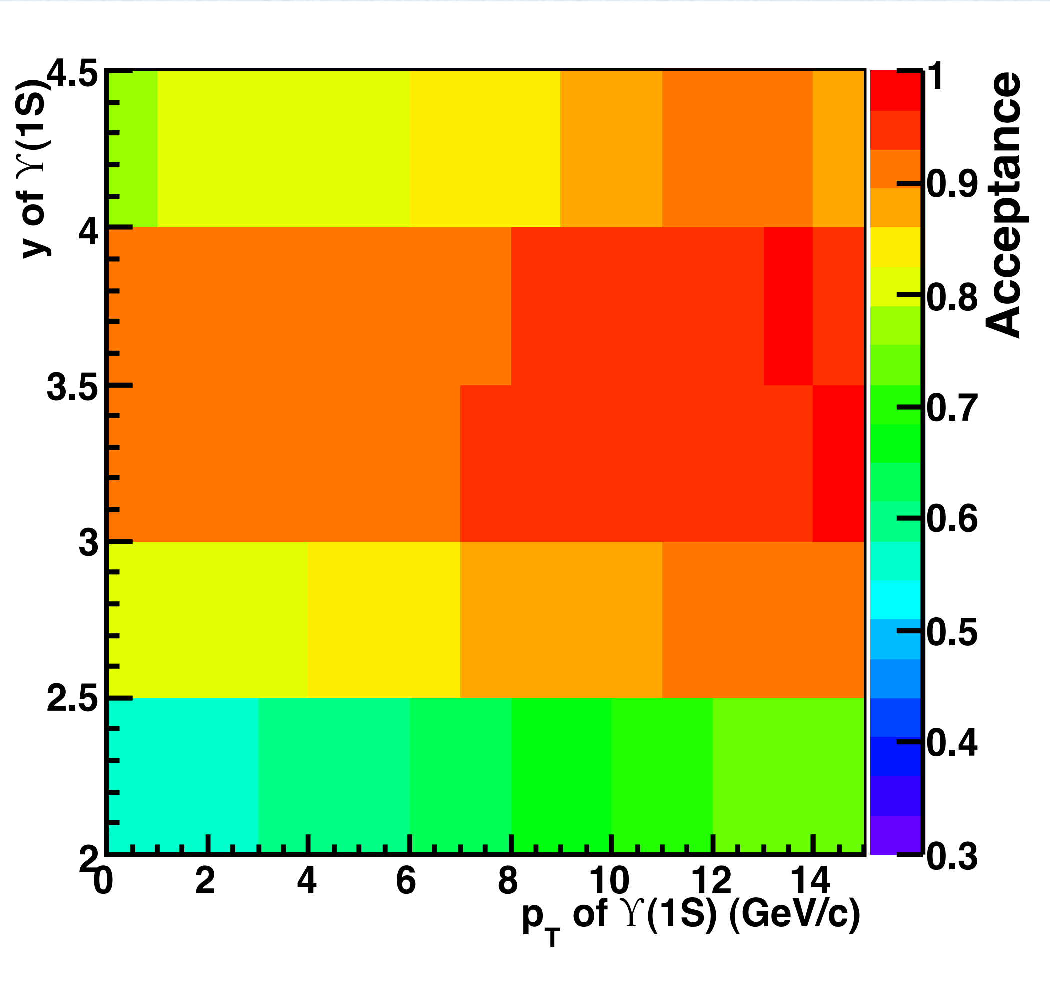


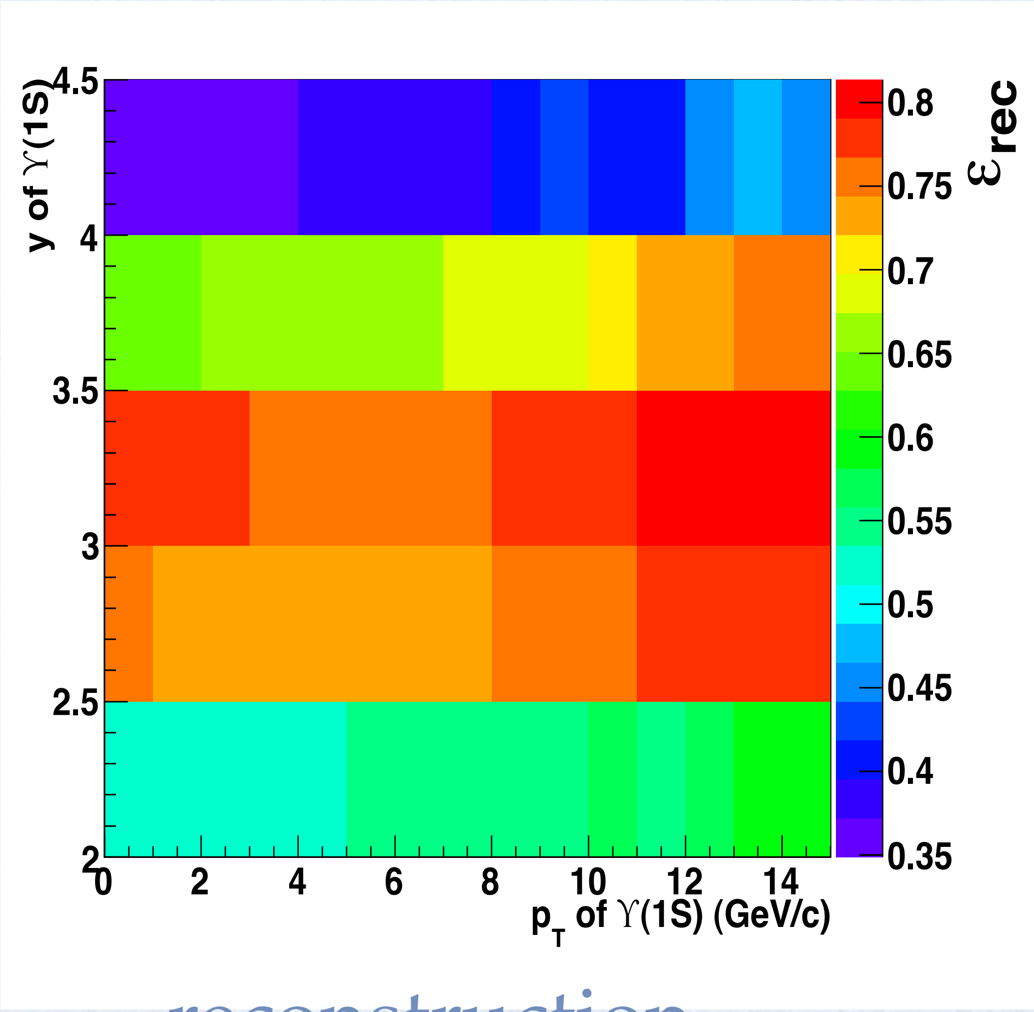






Υ(1S) efficiency





geometric acceptance

reconstruction efficiency

obtained from fully simulated events